The effects of simulated ulnar deviation on metacarpophalangeal joint implant failure

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Introduction

One-piece silicone (silastic) arthroplasties have been used successfully to treat symptomatic finger metacarpo-phalangeal (MP) joint and proximal inter-phalangeal (PIP) joint arthritis (Trail et al. 2004). The implants do not however, last as well as the hard bearing arthroplasties of major joints in the upper and lower limbs. This is in spite of the fact that implant testing originally suggested that the Swanson silastic implant could withstand 400 million cycles “without evidence of breakdown” (Swanson 1972) and no fractures were reported in five implants after 10 million cycles (Weightman et al. 1972). It was felt that the earlier failure was due to bone spikes initiating tears in the silicone which then propagated (Swanson 1972). This led to the development of grommets which were initially felt to be beneficial (Rittmeister et al. 1999; Schmidt et al. 1999). Longer term review has however suggested no benefit (Trail et al. 2004). Subsequent testing with a jig with pinch force led to fracture of a Swanson size 2 implant in 1 million cycles (Joyce and Unsworth 2000). This is more compatible with clinical experience where there have been reports of earlier failures even within 14 months (Weightman et al. 1972); the largest ever review of silicone MP joint arthroplasties showed that the outcomes were worse in patients who had had successful thumb carpometacarpal and MP joint arthrodeses (Trail et al., 2004). This further implies that lateral pinch forces increase the stresses on the implants leading to earlier failures.

Most MP joint arthroplasties and some PIP joint arthroplasties drift into ulnar deviation (Blair et al. 1984; Kay et al. 1978; Wilson et al. 1993). This is associated with poorer outcomes, which might be improved by crossed intrinsic transfers (Trail et al. 2004). No implants have been tested specifically in a jig with ulnar deviation to assess the effect of that on silicone finger joint wear and failure.
The aim of this study was to test whether movement of finger implants in a test rig causes more wear and implant failure in ulnar deviation than in neutral. We tested the null hypothesis that there would be no difference.

Methods and Materials

A mechanical test rig was designed and constructed (fig 1) to test 12 size 6 silicone MP joint implants supplied by Osteotec (fig 2). The rig consisted of an aluminium beam with 12 stations to hold the distal stems of the finger joint implants driven by a slider crank mechanism to cyclically flex the implants. Cavities to receive the stems of the finger joints were moulded using bone cement with a tapered steel former to create shaped recesses into which the stems fitted after the cement had cured. The stems were a close but not tight fit replicating the insertion into the intramedullary bone cavity in vivo. The finger joint implants were tested in groups of four implants in 0^0, 10^0 and 20^0 of deviation simulating ulnar deviation following implantation.

The rig was cycled at 1.5Hz with an arc of motion from 0^0- 90^0 simulating full extension to full flexion. The implants were submerged in a bath of Ringer's solution at 37^0C throughout the experiment. The rig was stopped and the implants were inspected with 3.5 x magnification every 500,000 cycles until a total of 4 million cycles.

Results

No silicone implant failed. All implants remained in situ throughout the experiment. There were minimal changes in any implants up to 1 million cycles. Signs of damage started to emerge after 1 million cycles primarily in the implants in greater deviation. For the purposes of clarity the side of the deviation is described as the ulnar side in simulation of the normal direction of drift following MP joint arthroplasties; the side opposite the deviation is described as the radial side. The observed signs of damage all increased consistently with increasing numbers of cycles. We report the results at 4 million cycles. The findings in the three groups were:

In 0^0 deviation there was symmetrical light wear either side of the necks of the implant i.e. where the stems of the implants reach the body (Fig 3). There was evidence of pistoning with signs of wear from impingement on the palmar distal aspect of the hinge (fig 3).

In 10^0 deviation there was light fretting to the radial side i.e. the side opposite to the deviation (fig 4). There were light striations to the palmar-radial and dorsal-ulnar aspects of the implants (fig 4). There was slight rotation of the body of the implant into supination and ulnar deviation.

In 20^0 deviation there was heavy fretting to the radial side of the neck of the implants. There were deep striations to the palmar-radial and dorsal-ulnar aspects of the implant (fig 5). On inspection these measured over 2mm in each implant whereas the surface changes at 0^0 and 10^0 were $\leq 1\text{mm}$. There was even more marked plastic deformation leading to rotation of the body of the implant into supination and ulnar deviation.

There were appreciable differences in the wear of the implants from the 0^0 group to the 10^0 group and even more to the 20^0 group. Thus the null hypothesis can be rejected.

Discussion

Silicone arthroplasties are known to fail. It has long been thought to be related to the extent of deviation of the joint (Oster et al., 1989; Clarke et al. 2001). Trail et al. (2004) clearly identified that joint replacement failure is more likely in fingers with greater deviation. Silicone fails by fracturing (tearing) of the surface which then propagates to catastrophic structural failure. Anything that reduces the risk of initiation and propagation of the tearing of the silicone should reduce the risk of joint replacement failure. Grommets were used to reduce the risk of tearing from sharp bone spikes. These do not appear to improve the outcome of these implants and have been abandoned (Trail et al., 2004).

More recently hard bearing implants have been developed and used with good results in osteoarthritis (Simpson-White et al. 2013) but are often too unstable in joints destroyed by inflammatory arthritis. There is still a need for soft (silicone) implants. There are a number of different silicone implants with the Swanson type implant the most commonly used (Trail et al. 2004). It is not established what is the best design of silicone implant (Trail et al., 2004).

This study has assessed more implants than any other biomechanical test of silicone finger implants. It is also the only study to assess several implants simultaneously in different conditions. We have shown that increasing ulnar deviation causing increasing silicone implant wear as recognised in clinical practice. The effect of the ulnar deviation would be likely to be greater if we also simulated pinch loading (Joyce and Unworth 2000) and simulated sharper bone edges (Swanson 1972).

There are weaknesses of this study: we only tested 12 types of one design of implant; the implants were not tested to destruction; the differences in wear were subjective but differed appreciably between the implants in the three groups; the rig simulated “normal” movement but patients rarely achieve a 90^0 arc of motion and the deviation will not be as rigidly fixed as in this jig; and we did not simulate the sharp bone spikes as we wanted to test ulnar deviation in isolation.

Despite the weaknesses of this study we have clearly shown for the first time that increasing “ulnar” deviation of silicone implants on its own leads to increasing wear of the implants. In vivo this will probably combine with sharp bone edges and lateral pinch forces leading to catastrophic failure. In future there need to be more efforts made to reduce the risk of tearing of the implant possibly by changes in the material and by surgical techniques aimed at reducing post-operative ulnar deviation.

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Figures

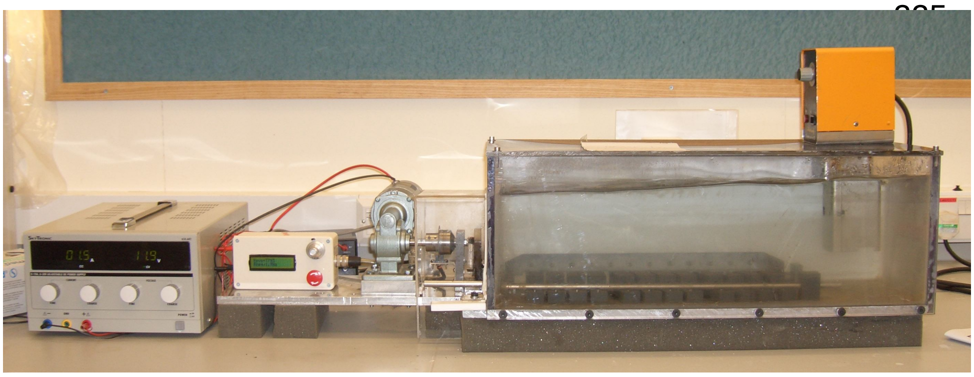


Fig 1 a

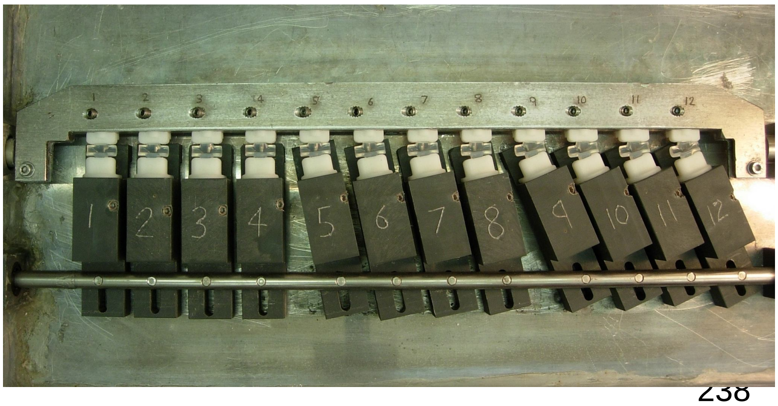


Fig 1c

Fig 1 b

Fig 1 The rig

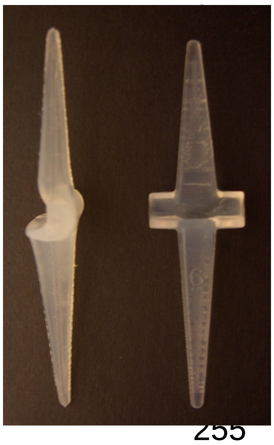
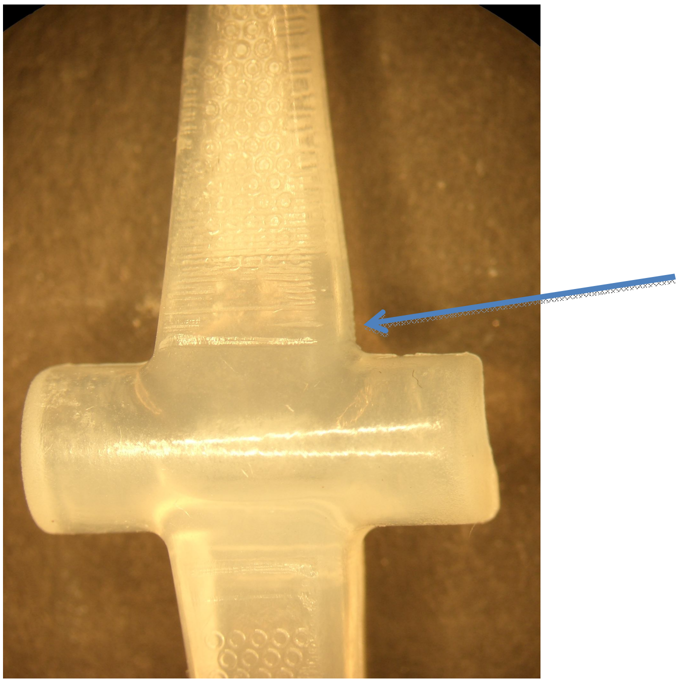


Fig 2 Osteotec size 6 implant prior to testing

Distal

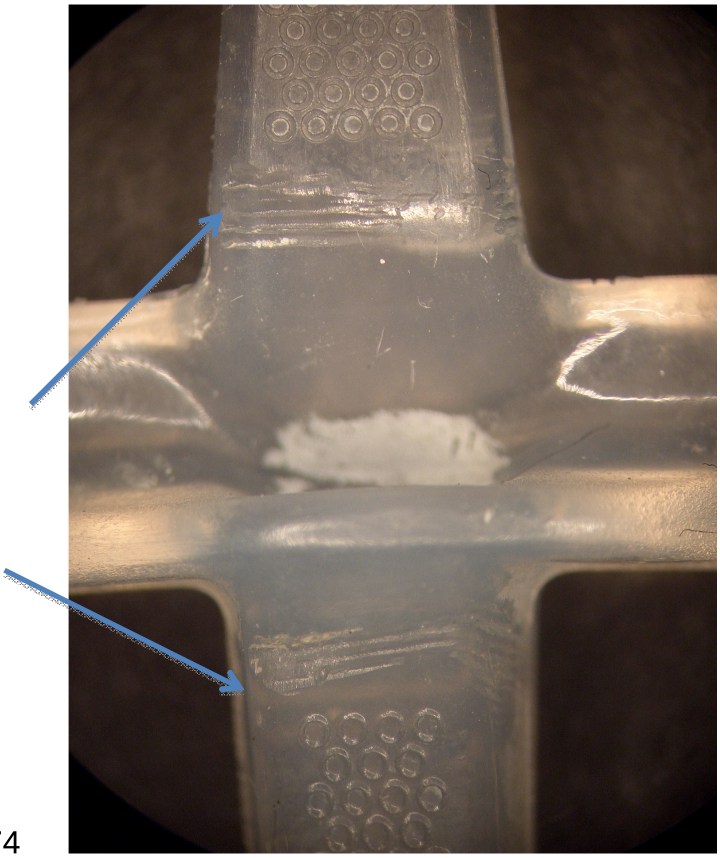


Minimal early dorsal ridging
on the stem of the implant

Radial Ulnar

Fig 3 Implants tested with 0^0 deviation and analysed after 4 million cycles

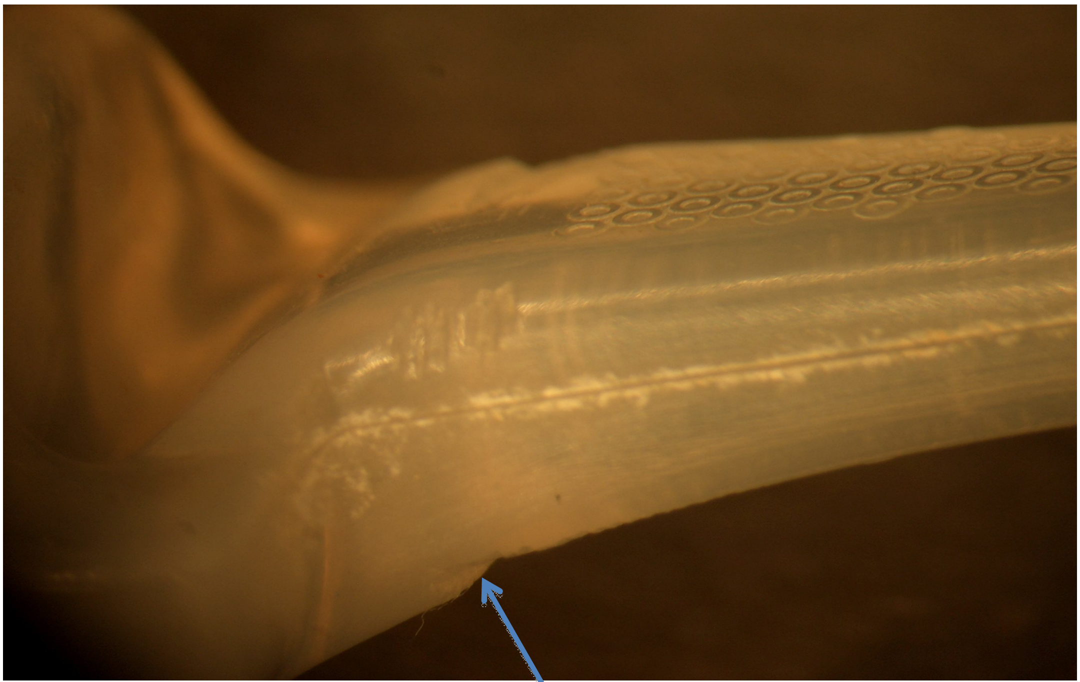
Distal



Arrows point to clear wear on the volar side of the implant stems

Fig 4 Implants tested with 10^0 deviation and analysed after 4 million cycles

Volar



Proximal

Dorsal Dorsal wear > 2mm deep Distal

Fig 5 Implants tested with 20^0 deviation and analysed after 4 million cycles